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Original article

Treatment of non-left main bifurcation lesions using the sirolimus-eluting stent: A comparison of chronic outcomes of cross-over single stenting and crush stenting

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KEYWORDS
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Summary
Background: It is said that the chronic outcomes of the two-stent technique for bifurcation lesions are inferior to that of cross-over single stenting. However, there are many cases where true bifurcations are difficult to treat by single stenting and, in particular, strategies for bifurcation lesions that are not left main trunk (LMT) bifurcations are still not clear.
Objective: This study aims to compare the usefulness of crush stenting with that of cross-over single stenting using the sirolimus-eluting stent (SES) on bifurcation lesions with the exclusion of LMT bifurcations.
Methods: Subjects were 92 consecutive patients (100 lesions) who underwent cross-over single stenting or crush stenting using SES for bifurcation lesions with the exclusion of LMT bifurcations. The patients were divided into 33 patients with 34 lesions, in whom the stent was implanted in the main vessel alone with the kissing balloon technique performed for the main vessel and side branch (Single-stenting group; S group), and 59 patients with 66 lesions, in whom the stent was implanted through crush stenting (Crush-stenting group; C group). The two groups were compared for target lesion revascularization (TLR) and major adverse cardiac events (MACE).
Results: There were no differences for TLR, with this conducted in the main vessel in 5.9% of S group and 4.5% of C group. There was no difference between the groups in MACE with 9.1% in S group and 8.5% in C group. No significant difference was seen in MACE-free survival rate in the chronic phase with 93.9% for S group and 94.9% for C group (P = NS).

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Conclusion: No differences in chronic clinical outcomes were revealed in a comparison between cross-over single stenting and crush stenting. Good clinical outcomes were achieved by both cross-over single stenting and crush stenting in the treatment of non-left main bifurcation lesions.

Introduction

In the era of the bare metal stent (BMS), treatment of bifurcation lesions posed problems such as low angiographic success and a high rate of side branch restenosis, making bifurcation lesions one type of lesion difficult to treat [1]. In particular, for lesions with a stenosis in the ostium of the side branch, side branch occlusion often occurred through a plaque shift during stent implantation in the main vessel, and it was reported that this could lead to in-hospital major adverse cardiac events (MACE) [2]. By inhibiting neointimal formation, the drug-eluting stent (DES) clearly showed less late loss than BMS [3]. Taking advantage of this characteristic, recent years have seen a variety of two-stent strategies (crush stenting [4], Y-stenting [5], T-stenting [6], and culotte stenting [7]) performed for the stenting of both the main vessel and side branch in true bifurcations. It has been reported that this prevents occlusion of the side branch and, compared to BMS, reduces restenosis in bifurcation lesions as well as the onset of late MACE [8]. But procedures currently performed by two-stent strategy still reveal a high percentage of side branch restenosis at about 20% [8—10] and it has been reported that compared to cross-over single stenting, there is also a higher incidence of stent thrombosis (ST) [8]. Notably, for left main trunk (LMT) bifurcation lesions, it became clear that the chronic outcomes of a two-stent strategy were inferior to that of cross-over single stenting, and it has been recommended as a general rule to perform cross-over single stenting in bifurcation lesions [11]. However, although there are many cases of high-risk true bifurcations that are difficult to treat by single stenting, strategies for bifurcation lesions that are not LMT lesions are still not clear.

Among the various two-stent strategies performed, it is highly possible that crush stenting proposed by Colombo et al. [4] in 2002 can fully cover both the main vessel and side branch regardless of bifurcation angle, and could thus be a strategy that can remove the gap between stents, which could occur through other strategies. Problems arose, however, in this stenting procedure, with a high rate of restenosis of the side branch ostium and the occurrence of ST in the chronic phase. In contrast, it has been reported in recent years that good outcomes are achieved by performing the kissing balloon technique (KBT) before the end of the procedure [12]. In addition, the incidence of ST reported in the outcomes of 2-year follow-up in the j-Cypher trial [13] was 0.63%, a much lower percentage than that of western countries. It is possible that the clinical outcomes of crush stenting on bifurcation lesions in Japanese patients do not necessarily match those reported in the West.

In this current study, we used the sirolimus-eluting stent (SES) to perform either cross-over single stenting or crush stenting in non-LMT lesions, and studied the usefulness of crush stenting in bifurcation lesions by comparing the chronic clinical outcomes of the two procedures.

Subjects and methods

Subjects

Subjects were 92 consecutive patients (100 lesions) who underwent cross-over single stenting or crush stenting using SES for bifurcation lesions with the exclusion of LMT bifurcations at our institution from June 2004 to May 2008, and whose clinical progress was able to be followed for 6 months or more after the procedure. The patients were divided into 33 patients with 34 lesions, on whom the stent was implanted in the main vessel alone with the KBT performed for the main vessel and side branch (Single-stenting group; S group), and the 59 patients, 66 lesions, on whom stents were implanted in both the main vessel and side branch through crush stenting (Crush-stenting group; C group). The groups were compared for target lesion revascularization (TLR), ST, MACE including cardiac death, acute myocardial infarction (AMI), TLR, coronary artery bypass grafting (CABG) in the chronic phase (760 ± 242 days). Subjects who did not fulfill all the following conditions were excluded: (1) a stenosis with a percent diameter stenosis (%DS) of 50% or more revealed in the main vessel or side branch near the bifurcation irrespective of morphology or bifurcation angle; (2) main vessel reference diameter (RD) of 2.5 mm or larger; (3) side branch RD of 2.0 mm or larger, with perfusion of the side branch believed to be clinically valuable; (4) treatment of both vessels judged necessary from angiographic findings irrespective of the presence of stenosis 50% or more in the ostium of the side branch. LMT lesions and restenosed lesions were also excluded. Bifurcation lesions were classified according to the Medina classification [14] (Fig. 1).

Quantitative angiographic analysis

Quantitative coronary angiography (QCA) measurements were obtained through CCIP 310 (Cathex Co. Ltd., Tokyo, Japan), measuring RD, lesion length, and minimum lumen

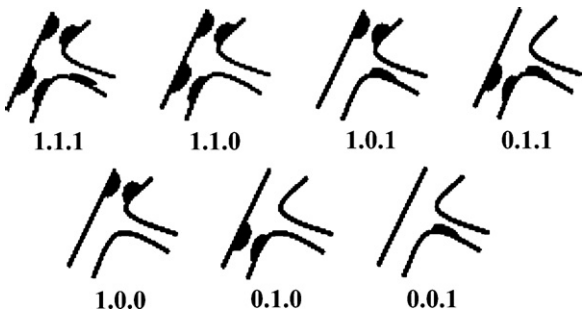

Figure 1 Bifurcation lesions were classified according to the Medina classification [14].

diameter (MLD) before and after the procedure and at late follow-up angiography. Angiographic success was defined as a residual stenosis of 20% or less in the main vessel and side branch, and thrombolysis in myocardial infarction (TIMI) III flow. Clinical success was defined as angiographic success achieved in the main vessel and no in-hospital MACE.

Angioplasty procedure

All patients were administered 100 mg of aspirin before the procedure along with 200 mg ticlopidine or 50—75 mg clopidogrel. Heparin 5000 U was also given before the procedure and maintained with the goal of keeping activated clotting time at 250—300 s. Dual antiplatelet therapy was continued after the procedure to the extent possible. Only the Cypher™ sirolimus-eluting coronary stent (Cordis, Johnson & Johnson, Miami, FL, USA) was used in this study.

In the S group, pre-dilatation was performed in the main vessel alone, or on both the main vessel and the side branch, followed by stenting of the main vessel. KBT was performed in all the cases after re-crossing the guide wire to the side branch. In the C group, after pre-dilatation of the main vessel and the side branch, the side branch stent was positioned for full cover of the side branch ostium, and before expansion, the main vessel stent was also positioned to cover the lesions. Modified crush stenting was mainly performed when a 6 Fr guiding catheter was used, with the balloon positioned in the main vessel so that it could crush the proximal end of the side branch stent. First, after expansion of the stent in the side branch, the system balloon and guide wire were retrieved, and following this, the pre-positioned stent or balloon was used to crush the part of the stent protruding into the main vessel. In modified crush stenting, this was followed by implantation of a stent in the main vessel. The guidewire was re-crossed to the side branch through the struts of the two stents covering the ostium of the side branch. A balloon was passed to the side branch and inflated at high pressure (12—16 atm) first in the side branch alone. KBT was then performed whenever possible. Inflation pressure for KBT was about 8 atm. Intravascular ultrasound (IVUS; Eagle-eye, Volcano Inc., Rancho Cordova, CA, USA) studies were conducted before and after the procedure in both groups if the IVUS catheter was able to cross the lesion. In principle, post-procedural study was conducted in the main vessel alone, with minimum stent area (MSA) measured. Additional ballooning of the main vessel was performed when underexpansion or malaposition was revealed, or when it was revealed that KBT caused deformation of the carina in the main vessel.

Clinical definition and follow-up

Follow-up of clinical progress was conducted through outpatient examinations, and late follow-up angiography was conducted at about 6—12 months after the procedure. MACEs were compared between the two groups conducted in-hospital and at the chronic phase (760 ± 242 days). The MACE-free survival rate was obtained through the Kaplan—Meier method and the two groups were compared. Restenosis in late follow-up angiography was defined as a lesion with a %DS of 50% or more in the stent and within 5 mm distal and proximal to the stent edge. In addition, TLR was defined as treatment conducted again on either the main vessel or the side branch in the presence of a stenosis with %DS of 50% or more. Using the ARC* [15] classification, ST was defined as fulfilling either the classification of definite or probable. Its rate of incidence was studied at each of these periods up to the chronic phase.

Table 1 Patient characteristics.

	Group S, $n = 33$	Group C, $n = 59$	P-value
Age (years)	66.9 ± 12.3	67.9 ± 11.7	n.s.
Male/female	28/5	50/9	n.s.
Diabetes mellitus (%)	15 (45.5)	30 (50.8)	n.s.
Hypertension (%)	16 (48.5)	28 (47.6)	n.s.
Hyperlipidemia (%)	21 (63.6)	32 (54.2)	n.s.
Smoking (%)	4 (12.1)	5 (8.5)	n.s.
Prior CABG (%)	2 (6.0)	4 (6.8)	n.s.
Hemodialysis (%)	2 (6.0)	3 (5.1)	n.s.
Diagnosis (%)			
SAP	18 (54.5)	31 (52.5)	
UAP	2 (6.1)	5 (8.5)	
AMI	0 (0)	2 (3.4)	n.s.
RMI	3 (9.1)	5 (8.5)	
OMI	10 (30.3)	16 (27.1)	
Extent of CAD (%)			
1-Vessel disease	5 (15.1)	15 (25.3)	
2-Vessel disease	16 (48.5)	28 (47.6)	n.s.
3-Vessel disease	11 (36.4)	16 (27.1)	
Ejection fraction (%)	58.5	61.1	n.s.

CABG, coronary artery bypass grafting; SAP; stable angina pectoris; UAP, unstable angina pectoris; AMI, acute myocardial infarction; RMI, recent myocardial infarction; OMI, old myocardial infarction; and CAD, coronary artery disease.

Statistical analysis

Continuous variables were expressed as mean value ± standard deviation. The Fisher's exact test or the χ^2 test was used for the association between two nominal variables, and the unpaired Student's t test was used in the comparison of two independent groups. In addition, the rate of MACE-free survival in the chronic phase was assessed by the Kaplan—Meier method and the Log-rank test was used for analysis. All statistical results were determined to be significant when $P < 0.05$.

Results

Patient and lesion characteristics

Table 1 shows patient characteristics. No significant difference was revealed between the two groups for age, gender, or clinical background. Table 2 shows lesion characteristics.

A significantly larger number of true bifurcation lesions according to the Medina classification [Type 1,1,1/1,0,1/0,1,1 was revealed in C group, with 16 (47.0%) in S group and 59 (89.3%) in C group ($P < 0.05$)]. There was no

Table 2 Lesion characteristics.

	Group S, $n=34$	Group C, $n=66$	*P*-value
Target vessel (%)			
RCA-AV/PD	6 (17.6)	8 (12.1)	
LAD-diagonal/HL	18 (53.0)	46 (69.8)	
LCx-OM	9 (26.5)	11 (16.6)	n.s.
SVG	1 (2.9)	1 (1.5)	
Angulation (%)			
Y type (<70°)	24 (70.4)	46 (69.7)	
T type (>70°)	10 (29.6)	20 (30.3)	n.s.
Bifurcation type (%)/medina classification			
Type 1,1,1	7 (20.6)	27 (40.9)	
Type 1,1,0	5 (14.7)	1 (1.5)	
Type 1,0,1	4 (11.8)	13 (19.6)	
Type 0,1,1	5 (14.7)	16 (24.5)	n.s.
Type 1,0,0	5 (14.7)	3 (4.5)	
Type 0,1,0	8 (23.5)	3 (4.5)	
Type 0,0,1	0 (0)	3 (4.5)	
True bifurcation (%)	16 (47.0)	59 (89.3)	<0.05
CTO lesion (%)			
Main vessel	2 (5.9)	3 (4.5)	n.s.
Side branch	0 (0)	0 (0)	n.s.
Calcified (%)			
Main vessel	5 (14.7)	15 (22.7)	n.s.
Side branch	4 (11.8)	15 (22.7)	n.s.

RCA, right coronary artery; AV, atrioventricular coronary artery; PD, posterior descending coronary artery; LAD, left anterior descending coronary artery; HL, high lateral branch; LCx, left circumflex artery; SVG, saphenous vein graft; and CTO, chronic total occlusion.

significant difference between the two groups for calcified lesions or bifurcation angle.

Baseline angiographic and procedural characteristics

The guiding catheter used was mainly 6 Fr in the S group (S group 85.3%; C group 30.3%) and 7 Fr in the C group (S group 14.7%; C group 69.7%; Table 3). Comparison of pre-procedural QCA findings revealed that while main vessel RD in the C group was not significantly different from that in the S group, side branch RD was significantly larger in the C group compared to the S group (S group vs. C group: main vessel 2.95 ± 0.42 mm vs. 3.04 ± 0.46 mm, P = NS; side branch 2.32 ± 0.48 mm vs. 2.46 ± 0.40 mm, $P < 0.05$). In addition, although there was no difference between the two groups in main vessel lesion length, side branch lesion length was significantly longer in the C group (5.4 ± 3.6 mm vs. 11.3 ± 5.5 mm, $P < 0.05$). Moreover, although there was no significant difference between the groups in %DS in the main vessel, it was significantly greater in the side branch of the C group (41.0 ± 27.7% vs. 66.8 ± 28.9%, $P < 0.05$; Table 4).

Table 3 Approach site and guiding catheter.

	Group S, $n=34$	Group C, $n=66$	*P*-value
Approach site (%)			
Radial artery	29 (85.3)	62 (93.9)	
Brachial artery	4 (11.8)	4 (6.1)	n.s.
Femoral artery	1 (2.9)	0 (0)	
Guiding catheter size (%)			
6 Fr	29 (85.3)	20 (30.3)	<0.05
7 Fr	5 (14.7)	46 (69.7)	

Table 4 Pre-procedural quantitative coronary angiography analysis.

	Group S, $n=34$	Group C, $n=66$	*P*-value
Main vessel			
RD (mm)	2.95 ± 0.42	3.04 ± 0.46	n.s.
Lesion length (mm)	25.5 ± 8.5	24.1 ± 9.2	n.s.
MLD (mm)	0.76 ± 0.34	0.82 ± 0.32	n.s.
%DS (%)	73.4 ± 10.3	73.2 ± 9.7	n.s.
Pre-TIMI grade 3	30 (88.2)	54 (81.8)	n.s.
Side branch			
RD (mm)	2.32 ± 0.48	2.46 ± 0.40	<0.05
Lesion length (mm)	5.4 ± 3.6	11.3 ± 5.5	<0.05
MLD (mm)	1.42 ± 0.66	0.81 ± 0.44	<0.05
%DS (%)	41.0 ± 27.7	66.8 ± 28.9	<0.05
Pre-TIMI grade 3	31 (91.2)	55 (83.3)	n.s.

RD, reference diameter; MLD, minimum lumen diameter; %DS, % diameter stenosis; and TIMI, thrombolysis in myocardial infarction.

No significant difference was revealed between the groups for stent diameter in the main vessel. KBT was performed in 34 lesions (100%) of the S group and 64 lesions (97.0%) of the C group, but no significant difference was shown (P = NS). KBT balloon size used was significantly larger in the side branch of the C group (2.25 ± 0.32 mm vs. 2.54 ± 0.44 mm, $P < 0.05$; Table 5).

IVUS was performed in 26 patients (76.5%) in the S group and 45 patients (68.2%) in the C group (P = NS). From post-procedural IVUS findings, additional ballooning was performed in the main vessel alone in 9 lesions (26.4%) of the S group and 9 lesions (13.6%) of the C group. Main vessel MSA after additional ballooning was 6.28 ± 1.12 mm^2 in the S group and 6.58 ± 1.33 mm^2 in the C group, showing no significant difference (P = NS; Fig. 2).

Angiographic results and in-hospital outcomes

No significant difference was revealed between the two groups in post-MLD in the main vessel, but this was significantly larger in the side branch of the C group (S group vs. C group: main vessel 2.89 ± 0.56 mm vs. 2.95 ± 0.49 mm, P = NS; side branch 1.95 ± 0.42 mm vs. 2.38 ± 0.45 mm, $P < 0.05$). Post %DS was significantly greater in the side branch of the S group (18.2 ± 15.5% vs. 2.1 ± 14.8%, $P < 0.05$; Table 6). There was no significant difference revealed for angiographic success in the main vessel, but in the side branch this was 79.4% in the S group and 92.4% in the

Table 5 Procedural characteristics.

	Group S, $n=34$	Group C, $n=66$	P-value
Main vessel			
Stent size (mm)	2.92 ± 0.48	3.03 ± 0.40	n.s.
Stent length (mm)	26.1 ± 10.3	26.9 ± 9.9	n.s.
Final balloon size (mm)	2.96 ± 0.44	2.99 ± 0.42	n.s.
Maximal inflation pressure (atm)	17.2 ± 2.6	17.0 ± 2.2	n.s.
Side branch			
Stent size (mm)	—	2.62 ± 0.24	
Balloon size (mm)	2.26 ± 0.42	—	
Stent/balloon length (mm)	17.0 ± 5.2	21.4 ± 8.2	<0.05
Final balloon size (mm)	2.26 ± 0.42	2.50 ± 0.33	<0.05
Maximal inflation pressure (atm)	9.7 ± 2.6	15.7 ± 2.0	<0.05
Kissing balloon post-stent implantation (%)	34 (100)	64 (97.0)	n.s.
KBT balloon size (mm)			
Main vessel	2.98 ± 0.49	2.96 ± 0.43	n.s.
Side branch	2.25 ± 0.32	2.54 ± 0.44	<0.05
KBT inflation pressure (atm)	8.5 ± 1.2	8.4 ± 1.2	n.s.
IVUS usage (%)	26 (76.5)	45 (68.2)	n.s.
Additional ballooning for main branch (%)	9 (26.4)	9 (13.6)	n.s.
Additional balloon inflation pressure (atm)	16.9 ± 2.5	16.7 ± 2.4	n.s.

KBT, kissing balloon technique; and IVUS, intravascular ultrasound.

C group, with a significantly higher rate in the C group ($P < 0.05$). No significant difference was revealed between the two groups in clinical success with 100% in the S group and 98.4% in the C group (P = NS). In the S group, 7 patients were not able to achieve a residual stenosis of 20% or less in the side branch after the procedure. In the C group, 3 patients were not able to achieve a residual stenosis of 20% or less in the side branch after the procedure. In addition, side branch occlusion after crush stenting was seen in 2 patients: 1 patient was TIMI 0 and the other was TIMI I, and no improvement was revealed in final angiography as well. There was only 1 case of in-hospital MACE, with onset of

Table 6 Angiographic result and in-hospital outcomes.

	Group S, $n=34$	Group C, $n=66$	P-value
Main vessel			
RD (mm)	2.93 ± 0.51	2.98 ± 0.48	n.s.
MLD (mm)	2.89 ± 0.56	2.95 ± 0.49	n.s.
%DS (%)	2.5 ± 7.2	2.6 ± 8.7	n.s.
Acute gain (mm)	1.89 ± 0.78	1.96 ± 0.53	n.s.
Pre-TIMI grade 3	34 (100)	66 (100)	n.s.
Side branch			
RD (mm)	2.37 ± 0.41	2.44 ± 0.41	n.s.
MLD (mm)	1.95 ± 0.42	2.38 ± 0.45	<0.05
%DS (%)	18.2 ± 15.5	2.1 ± 14.8	<0.05
Acute gain (mm)	0.61 ± 0.58	1.58 ± 0.53	<0.05
Pre-TIMI grade 3	34 (100)	64 (97.0)	n.s.
Angiographic success (%)			
Main vessel	34 (100)	66 (100)	n.s.
Side branch	25 (79.4)	61 (92.4)	<0.05
Clinical success (%)	100	98.4	n.s.
In-hospital MACE (%)			
Cardiac death	0 (0)	0 (0)	n.s.
AMI	0 (0)	1 (1.5)	n.s.
CABG	0 (0)	0 (0)	n.s.

RD, reference diameter; MLD, minimum lumen diameter; %DS, % diameter stenosis; MACE, major adverse cardiac event; AMI, acute myocardial infarction; and CABG, coronary artery bypass grafting.

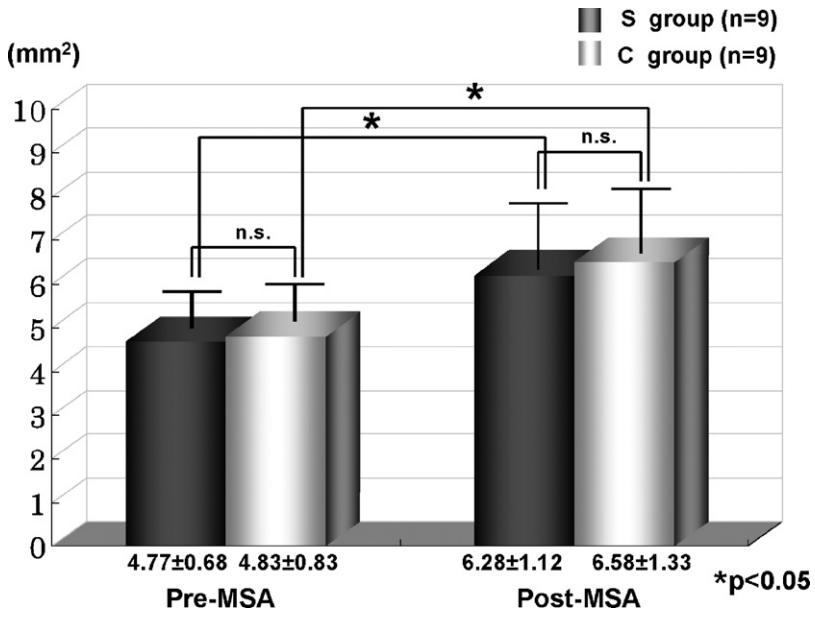

Figure 2 Additional ballooning was performed when intravascular ultrasound revealed underexpansion in the main vessel. The two groups were compared for minimum stent area in the main vessel before and after additional ballooning. Minimal stent area (MSA) significantly increased in both groups following dilatation, but no significant difference was revealed in a comparison between the groups for MSA before and after additional ballooning. C group, Crush-stenting group; S group, Single-stenting group.

AMI in 1 patient in the C group due to side branch occlusion during the procedure.

Follow-up results

Late follow-up angiography was conducted at 8.1 ± 3.7 months after the procedure in the S group and at 8.0 ± 4.3 months in the C group. Although no significant difference was revealed between the two groups in MLD or %DS in the chronic phase, late loss in the side branch was significantly larger in the C group (main vessel 0.09 ± 0.46 mm vs. 0.11 ± 0.40 mm, P = NS; side branch 0.26 ± 0.41 mm vs. 0.56 ± 0.62 mm, $P < 0.05$). Main vessel restenosis occurred in 2 cases (5.9%) in the S group and 3 (4.5%) in the C group (P = NS), and side branch restenosis occurred in 5 cases (20.0%) in the S group and 8 (13.1%) in the C group, with no difference between the groups (P = NS). No difference was revealed for TLR of the main vessel, with 2 (5.9%) in the S group and 3 (4.5%) in the C group, and no significant difference was seen for the side branch as well with 1 (4.0%) in the S group and 2 (3.3%) in the C group (Table 7). There was no difference between the groups for MACE in the chronic phase (mean follow-up period of 760 ± 240 days), with 9.1% in the S

Table 7 Follow-up angiographic result.

	Group S	Group C	*P*-value
Main vessel			
n	34	66	
RD (mm)	2.95 ± 0.55	2.96 ± 0.41	n.s.
MLD (mm)	2.80 ± 0.45	2.90 ± 0.38	n.s.
%DS (%)	11.3 ± 10.2	13.8 ± 9,8	n.s.
Late loss (mm)	0.09 ± 0.46	0.11 ± 0.40	n.s.
Restenosis (%)	2 (5.9)	3 (4.5)	n.s.
Target lesion revascularization (%)	2 (5.9)	3 (4.5)	n.s.
Side branch			
n	25	61	
RD (mm)	2.29 ± 0.37	2.38 ± 0.35	n.s.
MLD (mm)	1.63 ± 0.36	1.76 ± 0.34	n.s.
%DS (%)	30.6 ± 18.2	27.3 ± 21.7	n.s.
Late loss (mm)	0.26 ± 0.41	0.56 ± 0.62	<0.05
Restenosis (%)	5 (20.0)	8 (13.1)	n.s.
Target lesion revascularization (%)	1 (4.0)	2 (3.3)	n.s.

RD, reference diameter; MLD, minimum lumen diameter; and %DS, % diameter stenosis.

Table 8 Follow-up clinical results.

	Group S, $n=33$	Group C, $n=59$	P-value
MACE (%)			
Cardiac death	1 (3.0)	1 (1.6)	n.s.
AMI	0 (0)	1 (1.6)	n.s.
CABG	0 (0)	1 (1.6)	n.s.
Target lesion revascularization	2 (6.1)	2 (3.3)	n.s.
Stent thrombosis (%)	0 (0)	2 (3.3)	n.s.

MACE, major adverse cardiac event; AMI, acute myocardial infarction; and CABG, coronary artery bypass grafting.

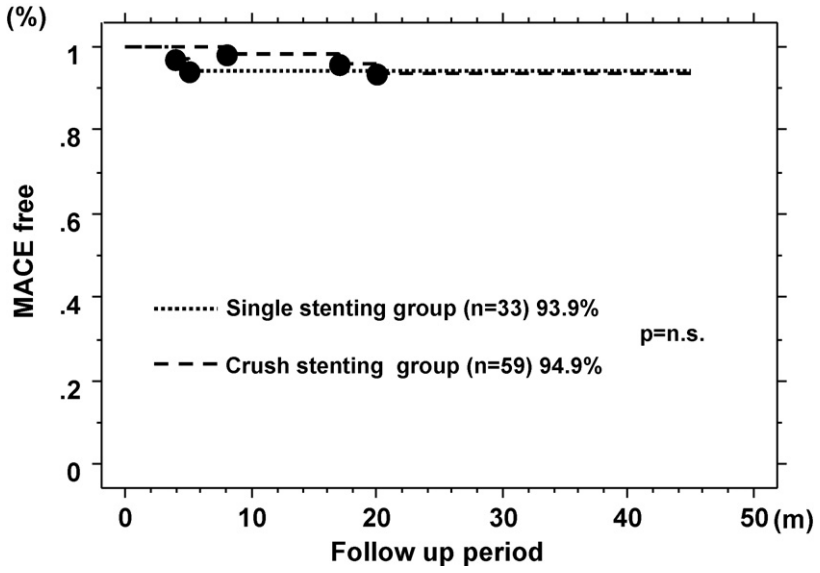

Figure 3 Major adverse cardiac events (MACE)-free survival rate in the chronic phase (760 ± 242 days) was compared by the Kaplan—Meier method. No significant difference was revealed between the two groups.

group and 8.5% in the C group (Table 8). There was no significant difference in MACE-free survival rate, with 93.9% in the S group and 94.9% in the C group (P = NS; Fig. 3). ST occurred in 2 cases in the C group. One was 13 months and the other was 20 months after the procedure. One patient had self-discontinued antiplatelet medication at an early period.

Discussion

As DES clearly reduce restenosis compared to BMS, they are currently being used in the treatment of various types of lesions. Among these, however, treatment of bifurcation lesions is one of the issues that remain to be resolved.

In this study, two strategies, crush stenting and cross-over single stenting for bifurcation lesions were compared using SES, but no difference was revealed between the two groups in chronic outcomes.

Restenosis and TLR

In this current study, no significant difference was revealed between the two groups for restenosis of the main vessel, and similarly for the side branch. In the era of the BMS, Yamashita et al. [16] studied the chronic outcomes of patients with BMS implantation for a bifurcation lesion who were treated by two-stent strategy (T-stenting, Y-stenting, V-stenting, and culotte stenting) or cross-over single stenting. They reported that main vessel restenosis was 23.1% in the single-stent group and 45.4% in the two-stent group, and side branch restenosis was 20.5% and 37.7%, respectively. On the other hand, in the same single-institution study, using DES, Colombo et al. [4] similarly compared the chronic outcomes of two-stent strategy (T-stenting, modified T-stenting, V-stenting, and culotte stenting) and cross-over single stenting for bifurcation lesions. It was reported that main vessel restenosis was 4.8% in the single-stent group and 5.7% in the two-stent group, and side branch restenosis was 14.2% and 21.8%, respectively. In this way, two-stent strategy for treatment of bifurcations using DES, as opposed to BMS, not only dramatically reduces the rate of main vessel restenosis, but could also improve restenosis of the side branch. However, even with DES implantation, two-stent strategy was not able to surpass the results of the single-stent group in improving the rate of side branch restenosis. As a cause of this, it was suggested that the frequent difficulties encountered in fully covering the lesion in the side branch ostium by T-stenting could lead to restenosis [4]. Expectations were held that crush stenting, a method that could fully cover the lesion at the side branch ostium, would further improve the rate of side branch restenosis. However, when viewing the outcomes in the early period when

the importance of KBT was unknown, side branch restenosis was 30%, remaining at a high rate similar to that of other two-stent strategies [17]. In recent years, the importance of final KBT has become clear, and recently Hoye et al. [18] reported good outcomes in the group undergoing KBT, with restenosis of 6.4% in the main vessel and 9.6% in the side branch. Ge et al. [12] similarly reported that the restenosis rate was 13.8% in the main vessel and 8.6% in the side branch in the group undergoing KBT, and stated that the side branch restenosis rate is influenced by whether or not KBT is performed. In our study, 97% of the Crush-stenting group was able to undergo KBT, and their chronic outcomes support the results of Ge et al. However, for patients who were able to undergo IVUS studies after KBT was performed, underexpansion of the stent in the main vessel was revealed in 26.4% of the S group and 13.6% of the C group. In the SIRIUS trial, Sonoda et al. [19] proposes a MSA >5.0 mm^2 as the end point in DES implantation. Although decisions were not made by measuring MSA in our study, the MSA of those undergoing additional ballooning consequently improved from 4.77 mm^2 in the S group and 4.83 mm^2 in the C group before additional ballooning to become 6.28 mm^2 and 6.58 mm^2, respectively, after additional ballooning. In the C group, there were cases of the carina displaced to the side of the main vessel after KBT, and notably, this was revealed more frequently in cases where the main vessel and side branch balloons used in KBT were the same or nearly the same in size. Thus it was suggested that performing KBT, using IVUS for evaluation of the main vessel in particular, and performing high pressure ballooning when underexpansion is revealed could further reduce the incidence of late MACE including TLR.

MACE

In this study, MACE-free survival rate did not differ between the groups. Notably, although restenosis was frequently revealed in the side branch in both groups, hardly any patients underwent TLR. Regarding ST, there was no acute or subacute ST in the 2 groups. IVUS evaluation after KBT, and performing additional ballooning when underexpansion is revealed could also reduce ST in the acute or subacute phase. However, very late ST was revealed in two patients in the C group alone. Predictors of ST are said to be AMI, long stent length [20], bifurcation [21], discontinuation of antiplatelet drugs, diabetes mellitus, renal failure, low left ventricular function [22], and stent fracture [23]. In this study, one patient self-discontinued antiplatelet medication at 13 months after the procedure, and stent fracture was revealed in another patient. One patient had an onset of AMI, and one patient had acute coronary syndrome but they survived to be discharged from the hospital. Although stent fracture cannot be predicted, its risks can be reduced through ways such as using a short stent. In cases where complex stenting like crush stenting is performed, it could be possible to lower the incidence of stent thrombosis by having the patient understand the importance of taking antiplatelets drugs as directed.

Study limitation

This study was limited by its small study population and by the fact that it was a retrospective study. It has been reported that provisional T-stenting is the favorable strategy for true bifurcations [24], but because this current study took the policy of performing crush stenting on such lesions, the C group consequently had a large percentage of true bifurcations, and moreover, a difference was also seen for side branch RD and a difference appeared in the lesion characteristics. Because bifurcation lesions also present issues such as late thrombosis, we believe a prospective study with a larger study population is necessary.

Conclusions

No differences in chronic clinical outcomes were revealed in a comparison between cross-over single stenting and crush stenting for non-left main bifurcation lesions. Good clinical outcomes were achieved by both cross-over single stenting and crush stenting in the treatment of non-left main bifurcation lesions.

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